THE SCATTERING OF POLARISED LIGHT BEAMS IN BIREFRINGENT SOLIDS

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1. Introduction

THE present Lord Rayleigh (1919) observed that when a beam of plane polarised white light is sent along the optic axis of a crystal of smoky quartz, its track, when viewed in a direction transverse to the beam, exhibits coloured bands. The phenomenon is obviously connected with the rotatory power of quartz which varies with the wavelength and has its origin in the polarisation of the Tyndall scattering by the inclusions present in the crystal. The phenomenon has also been photographed in perfectly clear quartz by the author (1947) using monochromatic ultra-violet $\lambda\,2537$ radiation of the mercury arc, the diffusion of light in this case having its origin in the atomic vibrations in the crystal. The effect is then much more striking owing to the high rotatory power of quartz in the ultraviolet. This investigation suggested the study of the scattering of plane-polarised light beams in birefringent solids which are not optically active.

A beam of plane-polarised light traversing a birefringent crystal divides into two beams polarised in perpendicular planes. These travel with different velocities but being everywhere coherent, they would combine and give a single elliptically polarised light beam, in which, however, the constants of ellipticity change periodically along the path. Hence, the track of the beam made visible by the scattered light should, in general, exhibit bands of fluctuating intensity. However, the case differs from that of optically active solids in several respects. *Firstly*, along the directions of single wave velocity, the light travels without undergoing any change in the state of its polarisation. There would then be no fluctuations in the intensity of the scattered light along the track. *Secondly*, the band width would vary with the direction of propagation. *Thirdly*, the azimuth of the electric vector in the incident light beam as well as the azimuth of observation are both important. When the incident light vector coincides with one of the principal planes of the crystal, the beam travels without any alteration in its state of polarisation and hence no fluctuations in its intensity would be observed

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in light scattering. On the other hand, the maximum changes in its state of polarisation would occur when the electric vector is inclined at 45° to the principal planes. In this case, the beam would be plane-polarised, alternately in and at right angles to the original azimuth. Viewed in either of these planes, the track would show the maximum fluctuations in intensity, while intermediately the track would appear of uniform brightness.

Now the distance traversed inside the crystal for a complete cycle to occur depends on the birefringence, and unless the length of the periodic cycle of changes is at least a millimetre or two, it would be difficult to observe the fluctuations of intensity along the track. Hence, crystals with small birefringence would be most suited for the experiment. However, even with crystals which are strongly birefringent, this difficulty could be overcome by sending the light beam very near to the optic axis. For example, with calcite which has a very large birefringence, a beam making an angle of 2° to the optic axis should give a band width of the order of a millimetre. Specimens to be suitable for exhibiting these phenomena should be large and perfectly clear single crystals preferably transparent to the ultraviolet λ 2537 radiation of the mercury arc, as that could then be employed to record the effects photographically. As the birefringence of crystals, in general, varies but little with wavelength, the band width would be proportional to the wavelength. If the single crystals are shaped into spheres and polished, both the direction of propagation and the azimuth of observation could be varied at ease for the convenient study of the phenomenon.

Pending the preparation of such crystal spheres suitable for the work, the phenomenon has been observed and studied by the author in plates of synthetic organic glasses. These often exhibit permanent strains and hence behave like uniaxial or biaxial crystals with very small birefringence. They also scatter light strongly, such scattering being well polarised. Employing sunlight filtered through a violet glass or monochromatic sodium yellow light λ 5893, all the points stated above have been successfully illustrated in the observations using them. Photographs, showing the effects, are reproduced on the Plates.

2. DESCRIPTION OF THE PHENOMENA

A narrow beam of plane polarised sunlight, filtered through a violet glass, was sent perpendicular to the optic axis of a rectangular plate of colourless and transparent plexiglas. The plate is a uniaxial solid with very small birefringence and its optic axis is parallel to its thickness. Three photographs of the track, taken in an azimuth inclined to the optic axis, are reproduced in Figs. 1 (*a*), 1 (*b*) and 1 (*c*), Plate III, the exposure in each

case being one minute. In the case of Figs. 1 (*a*) and 1 (*b*), the incident light vector was inclined at about — 40° and + 40° to the optic axis respectively. These figures show fluctuations in intensity along the track and there is just about one band and a half for 9 centimetres. The maxima of intensity of Fig. 1 (*a*) coincide with the minima of Fig. 1 (*b*) and *vice versa*. Owing to the refraction of light taking place when the diffused light emerges obliquely to the face normal to the optic axis, the incident light beam was only polarised with the electric vector at an angle of 40° to the optic axis and not at the optimum angle of 45° to the axis. The azimuth of observation in each case was about 75° to the axis. In the case of Fig. 1 (*c*), the incident light vector was parallel to the optic axis, and hence the track is of uniform brightness.

Now, instead of varying the azimuth of the incident light vector, if that of observation is varied the same sequence of phenomena is obtained, provided that the incident light vector is at 45° to the optic axis. When white light is used, coloured bands are seen in the proper azimuths since the band-width varies with the wave-lengths.

In the case of two yellow plates of transparent bakelite, the effect has been photographed and is reproduced in Figs. 2 (*a*), 2 (*b*) and 2 (*c*) in the case of one and in Figs. 3 (*a*), 3 (*b*) and 3 (*c*) in the other case. As these plates have a larger birefringence, they exhibit a number of bands instead of just one and a half as in the case of plexiglas. To prevent overlapping of higher orders of the bands, the monochromatic yellow light of the sodium lamp was used in these two cases, and the tracks were photographed in about 2 to 4 hours using HP3 plates. Even in monochromatic light, the higher orders of the bands lose gradually their clarity. They are also curved and their curvature varies with their position. All this is due to the irregular birefringence of the bakelite. In spite of the yellow light employed, the intensity along the tracks gradually falls off with the advance of the beam, due to the absorption of light by the bakelite.

In conclusion, the author wishes to thank Sir C. V. Raman for his constant encouragement and guidance throughout the course of the investigation.

3. SUMMARY

As a plane-polarised light beam advances inside a birefringent solid, its state of polarisation, in general, undergoes a periodic cycle of changes. In light-scattering transverse to the beam, these changes manifest themselves as fluctuations in intensity along the track: there would be one band for one complete cycle. The bands would be most marked when *both* the azimuth
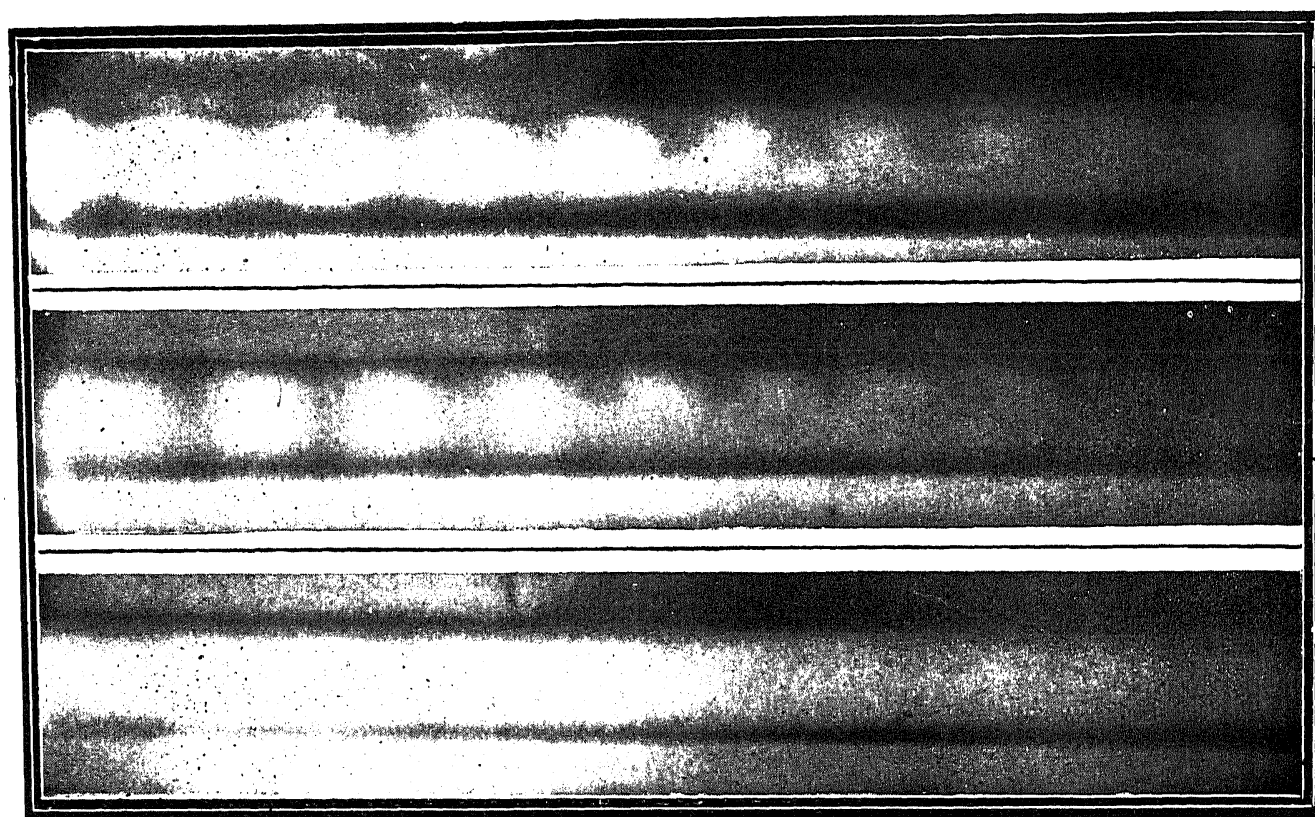
FIG. 2. Tracks of polarised λ 5893 beam traversing birefringent bakelite I

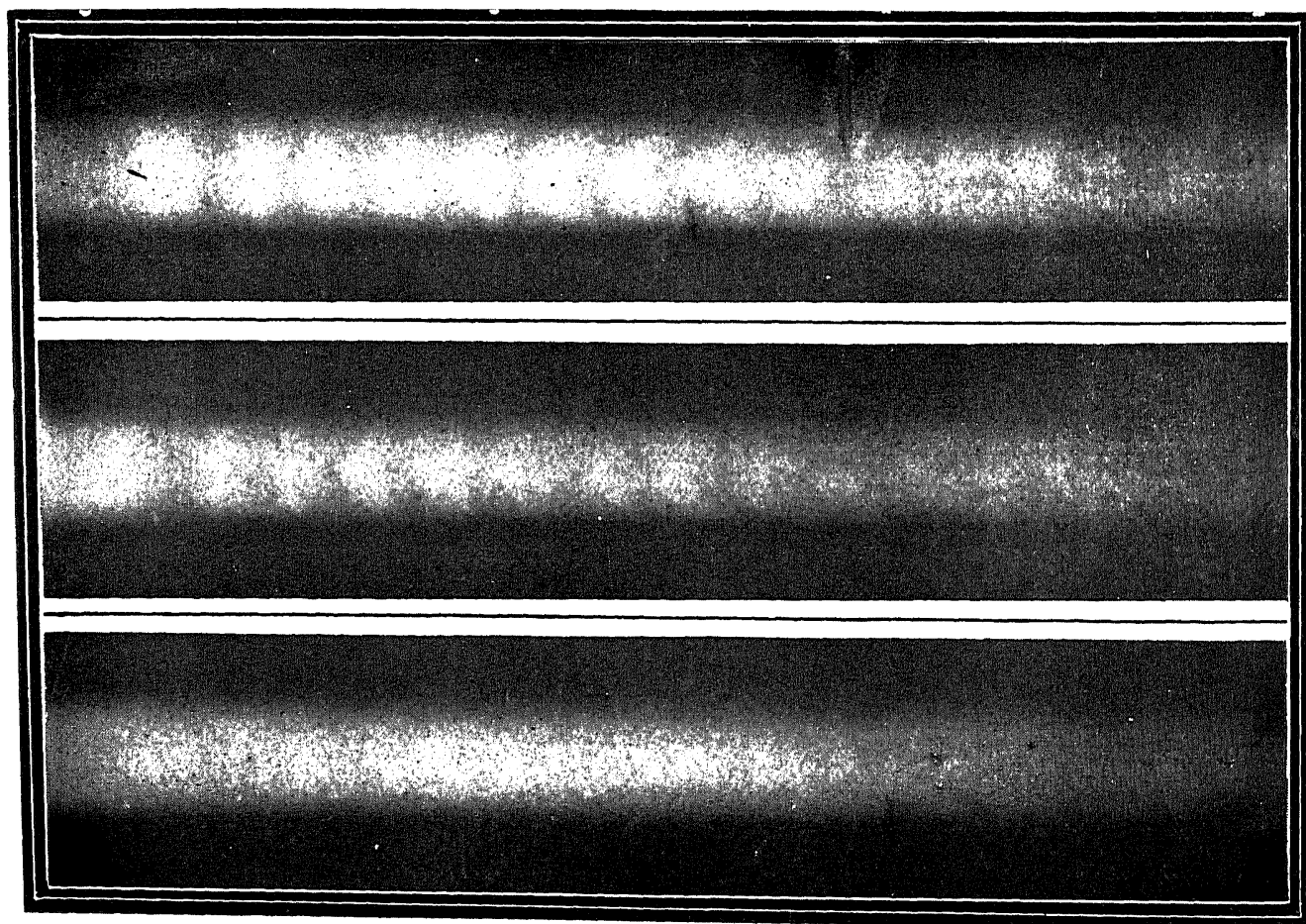FIG. 3. Tracks of polarised λ 5893 beam traversing birefringent bakelite II

of the incident light vector as well as that of observation are inclined at 45° to the principal planes of the solid. On the other hand, the fluctuations in intensity would disappear when *either* of the azimuths coincide with one of the principal planes. Using three synthetic organic glasses with permanent strains and hence behaving like uniaxial or biaxial crystals with very small birefringence, these effects have been studied and photographs, showing these, are reproduced in the paper.

REFERENCES

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